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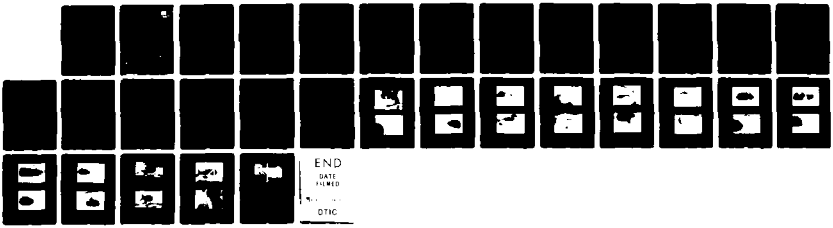

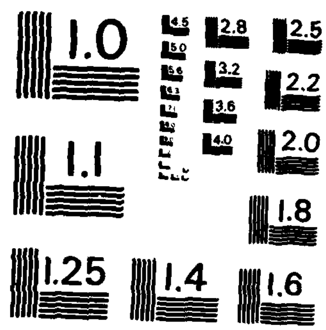

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Aerostat icing problems

B. Hanamoto

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This report describes laboratory tests to determine the effectiveness of a copolymer coating on a balloon to minimize ice build-up problems when operating in sleet, freezing rain or other ice-forming conditions. Methods for deicing the surface after an ice cover forms are also described. A small-scale balloon was used for the laboratory tests. A full-scale prototype was also partially coated with the copolymer to test its effectiveness as an icing control measure.

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PREFACE

This report was prepared by Ben Hanamoto, Research General Engineer, Ice Engineering Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The work was performed for the U.S. Air Force Geophysical Laboratory, Hanscom Air Force Base, Massachusetts, under MIPR FY71218200015.

Technical review of the report was performed by Guenther Frankenstein (Chief, IERB) and Stephen Den Hartog of CRREL.

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AEROSTAT ICING PROBLEMS

B. Hanamoto

Introduction

Icing of structures and systems that are exposed to a cold environment has always been a problem. Mechanical systems cease to operate properly, the weight of ice on structures causes instability and failure, and, on antennas, signal transmission and reception are hindered. Heat is a solution, but in many cases it is not feasible. Placing a cover over the system has proved successful in the case of satellite communication antennas. Another solution is to coat the surface on which ice forms to control the formation or to allow easier removal once it has formed.

Several years ago the U.S. Army Cold Regions Research and Engineering Laboratory developed a coating to facilitate ice removal from the walls of navigation locks in the inland waterways system. This coating was also used, with limited success, on satellite communication antenna dishes to minimize ice buildup and to make ice removal easier. The basic coating material is a long-chain block copolymer which reduces the adhesive bond strength between the coated surface and the ice formed on it. Heat and vibration were effective means for removing ice from the coated lock walls. A warm glycol wash was effective on the antenna dishes when ice did form, to keep operating downtime to a minimum and to keep the ice from interfering with signal reception.

The Air Force Geophysical Laboratory at Hanscom AFB outside of Boston, Massachusetts, recently asked CRREL to conduct deicing tests on a balloon system which will be required to operate in regions where icing of the surface can be encountered. The balloon surface is made of Tedlar, and air and helium are the inflating gases. The system will fly at various altitudes while tethered to a ground mooring system. The margin between lift and payload is narrow, and the balloon cannot tolerate much additional weight due to ice buildup on the surface. Once ice starts to form, means for removing it while the balloon is in flight will be needed.

This report describes the application of a coating to facilitate shedding of ice from the surface of this system.

Test Procedures

Tests to determine the effectiveness of the copolymer coating on the balloon were conducted in the CRREL Ice Engineering Facility. The Tedlar bag was obtained from the TCOM Corporation of Columbia, Maryland, manufacturers of the balloon. The test specimen was a bag with hemispherical ends and a volume of about 3.1 m^3 (110 ft^3). Half (one end) of the bag was coated with the copolymer solution, the coated area being about 5.7 m^2 (61 ft^2). The surface was first cleaned with toluene and allowed to dry, and the copolymer solution was then applied with a brush. On a small sample, a one-coat application increased the weight by 7.3 g/m^2 (0.15 lbf/100 ft^2). On the test bag the increase in weight was 9.47 g/m^2 (0.19 lbf/100 ft^2). The total weight of the bag, filled with air to a pressure of 5 cm (2 in.) water at a room temperature of 20°C (68°F), and with half the surface coated, was 3.46 kg (7.63 lbf).

The bag was filled with air and hung in a coldroom where the temperature could be held constant at any value down to −23°C (−10°F). It was hung from a load cell so that the amount of ice formed on or shed from its surface could be measured. Bag inflation pressure was monitored with a water manometer. Thermistors and the room temperature control dials were used to maintain the desired temperatures during the tests.

To ice the balloon cold tap water (4.4°C or 40°F) was sprayed in a fine mist onto the surface with the room temperature at two different below-freezing settings. The icing system consisted of a water supply and a syphon hose and compressed air supply connected to a Spraying Systems Company air-atomizing 1/4 JBC series spray nozzle with air and water inlets parallel to the axis of projected spray. The aircap in this setup produced a narrow, full-cone, round spray pattern. The nozzle was held about 1 m from the surface and the head was moved at about 1 m/s during spraying. Icing was conducted at two temperatures, −4.4°C ± 1° and −2.8°C ± 1° (24°F ± 2° and 27°F ± 2°). At both temperatures, the uncoated end grew a smooth sheet, the spray hitting the surface and forming a film before freezing. On the coated end, droplets formed on the surface, coalesced, formed rivulets and flowed down the side. Both rivulets and droplets eventually froze. The sheet formed readily on both the top and bottom halves of the

bag. But below the midline of the bag, where the surface started to curve under, it was difficult to form a smooth sheet, even on the uncoated end.

Attempts were then made to deice the bag. Two schemes were used: a deflation/inflation cycle and an inflation/deflation cycle. Several initial inflating pressures were tested. Following the cycles, a wooden club was used to induce vibrations and shed the ice.

The first tests were made to obtain some idea as to what happened when a deicing cycle was initiated. The effects of a change in inflation pressure on the results were looked at, and icing procedures and temperature effects were determined.

Following these tests, a testing procedure was designed which best showed the difference between the uncoated and copolymer-coated sections of the bag when ice was formed on the surface and a deicing cycle performed. This final test procedure was decided on after talks with George McPhetres, the Project Engineer from AFGL. There were two deicing mechanisms on the prototype balloon: an inflation/deflation cycle and a fairly high-frequency vibrator. The final procedure called for an initial bag inflation pressure of about 5 cm (2 in.) water, icing for a total of 25 minutes on each side at -2.2°C (28°F), followed by the inflation/deflation cycle. The inflation cycle was continued to 38 cm (15 in.) water and then the bag was deflated to about 2.5 cm (1 in.) water. Vibration was induced at this deflated pressure by a tap with a club.

The inflation pressure, ambient temperature, icing time, and weight of ice accumulated on the bag were monitored and recorded for each test. The main item of interest was to observe the effect of the deicing method used — the inflation/deflation and deflation/inflation cycles. This was to be the basis for determining the effectiveness of the copolymer coating as an aid in minimizing the icing problem.

Test Results

The results of all tests are presented in Appendix A. Photographs of some tests and of the effects of the deicing cycle are presented in Appendix B.

In the first tests of the series the entire bag was iced, with equal spraying time for the copolymer-coated and uncoated halves. During the

deicing inflation cycle, cracks that formed in the ice sheet always originated in the coated end. Since the ice sheet was continuous from the coated end to the uncoated end, the cracks propagated into the uncoated portion. During the deflation cycle, the ice sheet tended to lift off the bag surface, starting at the crack sites. It appeared (by a change in coloration of the ice sheet) that most of the ice lifted off the coated end, but that only part of the ice on the uncoated end lifted. In many cases, the ice fell off both ends of its own accord during the deflation cycle, especially on the lower, undercurved part of the bag.

Tests were also conducted with only half the bag iced.

The final tests were conducted with a plastic strip placed between the coated and uncoated ends during icing. After the bag was iced the strip was removed and an un-iced gap remained between the two ends. A more meaningful evaluation of the effectiveness of the coating could thus be made.

During Test 22 the first cracks appeared at 12.9 cm (5.1 in.) water on the coated end and at 15.7 cm (6.2 in.) water on the uncoated end. In Tests 23, 24 and 25, the first cracks appeared at 15.7, 15.7 and 15.2 cm (6.2 and 6.0 in.) water on the coated end. The first cracks on the uncoated end appeared at 23.8, 25.4 and 26.8 cm (9.4, 10.0 and 10.6 in.) water during the same tests. As the pressure increased, multiple cracks appeared, first on the coated end and then on the uncoated end with further pressure increases.

During Test 22, at 35.0 cm (13.8 in.) water during the inflation cycle, 0.28 kg (0.62 lbf) of ice was shed from both ends, with more ice coming off the uncoated end. Upon deflation, more ice shed off the uncoated end — 0.32 kg (0.71 lbf). At 4.4 cm (1.7 in.) water, 0.32 kg (0.71 lbf) of ice was shed from the coated end. All this shedding from both ends was unassisted. Total ice formed was 3.79 kg (8.4 lbf). With one tap, 2.65 kg (5.8 lbf) of the ice fell off.

During Test 23, 0.62 kg (1.4 lbf) of ice shed unassisted from the coated end during the inflation cycle. This was about 30% of the ice formed on that end. Almost none fell off the uncoated end. No more ice shed during the deflation cycle. At 4.3 cm (1.7 in.) water, one tap removed 2.90 kg (6.4 lbf) or about 82% of the total ice formed. Most of the

remaining ice was on top of the bag where the surface was nearly horizontal.

Some ice (0.31 kg) (0.68 lbf) shed from both ends unassisted in Test 24 during the inflation cycle. No more unassisted shedding occurred during the deflation cycle. With one tap at 1.3 cm (0.5 in.) water, 3.32 kg (7.3 lbf) of ice fell off, or 87%.

In Test 25 there was some self-shedding of ice from both ends during the inflation cycle, 0.26 kg (0.57 lbf) or 10% at 39.0 cm (15.4 in.) water. The ice sheet lifted off the surface when the cracks formed, as was the case in all the tests. At 8.3 cm (3.3 in.) water during the deflation cycle, much of the ice on the coated end came off unassisted -- 0.67 kg (1.5 lbf), or 32% of the total ice formed on that end. One tap dislodged 2.9 kg (6.4 lbf), or 82% of the total ice grown on the bag.

The results of these tests showed that the copolymer coat causes cracks to occur at lower inflation pressures than on an uncoated surface. Crack formation also breaks the bond between the ice sheet and the surface and allows the sheet to lift. Multiple cracks, like a shattering of the ice sheet, occurred on the coated end at lower pressure than on the uncoated end. The amount of multiple cracking was greater on the coated end, and since the cracking resulted in lifting of the ice sheet, more ice was lifted off the surface on the coated end. More self-shedding occurred from the sheet on the coated end during a deicing cycle. This must have resulted from more of the sheet being lifted. After one inflation/deflation deicing cycle, the vibration caused by one tap on the surface removed most of the ice, at least 80% or more.

The combination of the inflation/deflation cycle and vibration appears to be an effective deicing means, and the copolymer coating allows for ice removal at lower inflation pressures.

Repair of Coated Surface

Two questions arose concerning repair of a balloon if a rip or tear occurred: If the surface was coated with the copolymer could it be cleaned so that the patch would stick? And could the patch be applied at low temperatures? A hot melt adhesive system made by the Dexter Corporation, consisting of the Hysol Model 4000 "gun" and Taylor Parker Company Type

1975 adhesive, was used to patch small sections of the Tedlar material. The glue gun was fitted with the standard three-hole 0.050 No. 197 SST nozzle and the 298 FG thermostat with an applicator temperature of 232°C. With an air pressure of 345 kPag (50 psig) on the gun, no problems were encountered in extruding the melted adhesive at temperatures of -2.5°, -8.0°, -10.5° and -23.3 °C (28°, 18°, 13° and -10°F). Laying a strip of adhesive on the surface and applying and smoothing the patch quickly produced a solid patch on the tear. Subsequent layering of single strips of the adhesive and smoothing of the patch over the entire length of the tear, with adequate overlaps on all sides, completed the repair. Copolymer-coated pieces of Tedlar were also patched. The patch area was washed with toluene and allowed to dry for 15 minutes before the patch was applied. To completely remove the copolymer film, the tear area was washed six times, the wash pad being changed each time. A patch as strong as the original material resulted after the torn area was cleaned in this manner.

Field Trials

Field trials of a prototype 708-m^3 (25,000-ft^3) balloon were conducted at the Camp Ethan Allen Training Center in northern Vermont during February and March of 1983. During these trials, atmospheric conditions where icing of the balloon would occur were expected. To test the copolymer coating, portions of the balloon were coated in the field on two occasions. The aerostat was moored to its ground platform and the copolymer was roller-applied from a "cherry-picker" type hoist. The surface was not cleaned. Ambient temperatures were -2.2° and 0°C (28° and 32°F) on the two dates. It appeared that a satisfactory coat was put on. The left top quarter from nose to tail and the top surfaces of the fins were coated, as was a section of the vertical fin. The effectiveness of the coating is still to be evaluated.

Conclusions

The copolymer coating causes a water spray to coalesce, forming droplets, before freezing when ambient temperatures are between -5.6° and -2.2°C (22° and 29°F), the temperature conditions of the laboratory icing tests. The average ice accumulation during a 25-minute period in the final

tests (Tests 22-25) was 2.1 kg (4.6 lbf) for the coated half of the test bag and 1.6 kg (3.5 lbf) for the uncoated half. The heavier accumulation was no doubt due to the forming of droplets rather than a film on the coated end. The most notable difference between the coated and uncoated ends of the bag was the pressure at which cracks formed and the ice sheet lifted from the surface. Crack formation started on the coated end at inflation pressures of about 15 cm (6 in.) water. During these same tests, cracks first appeared on the uncoated end at about 25 cm (10 in.) water. Multiple cracks appeared with increases in the inflation pressure, more on the coated end. Along with the cracks, the ice sheet lifted off the surface at the crack sites. Much more lifting was noted on the coated end. More natural shedding was observed on the coated end as the deicing cycle of inflation/deflation was performed. After a deicing cycle, one tap was usually enough to shed most of the ice.

Therefore, with a copolymer coating and a deicing cycle of inflation from the initial 5 cm (2 in.) water to about 20 cm (8 in.) water and deflation down to 5 cm (2 in.) water again, the ice sheet should form multiple cracks and experience some natural shedding. Add to this a vibration cycle and it should be possible to shed any ice formed on the surface. Without the coating, a higher inflation pressure would be needed for crack formation.

The hot glue gun is capable of extruding adhesive down to an ambient temperature of -23°C (-10°F) (the lowest temperature possible in the laboratory coldroom). By laying one strip of adhesive and applying a patch, followed by single strips of glue and smoothing of the patch, any length of tear can be repaired down to this temperature. The copolymer film can be removed by six washings with toluene and a sound patch can be applied to a tear in the cleaned area.

Both laboratory tests and field trials have been conducted with the copolymer coating on the Tedlar balloon. The laboratory tests reveal that the coating holds some promise as an aid in removing ice formed on the surface. The field trials have yet to be evaluated. By combining the results of the two, a scheme to reduce ice buildup and enhance ice removal from the surface of an aerostat flying in the cold regions may be possible.

APPENDIX A: RESULTS

Date	Press. (cm HOH)	Weight (kg) Uniced	Weight (kg) Iced	Temp. (^{o}F)	Icing Time (min.)	Remarks
14 Dec 82	11.2	3.45	4.33	25		Checking icing procedure, coated side only.
15 Dec 82	19.0	3.63	5.38	25		Checking test procedures, iced both sides. Deflating from 19 cm to 1 cm HOH. Cracks on both sides, sheet appears lifted. Tap of surface and ice off.
20 Dec 82	25.6	3.65	5.94	25		Deflate to 2 cm HOH: cracks on coated side, sheet lifted. No lift off on uncoated side. Inflate to 38 cm HOH: No shedding of ice. Deflate to 2 cm HOH: One tap and ice off coated side, partially off on uncoated side.
21 Dec 82 ICED UNCOATED SIDE ONLY	28.7	3.72	5.33	26		Deflate to 1.5 cm HOH: Sheet appears partially lifted, no cracks. Inflate to 38 cm HOH: Large crack 6.4 mm wide. Deflate: @ 5.0 cm HOH, sheet lifted 25 mm at crack. No shedding. Entire sheet appears lifted. Inflate to 37.8 cm HOH: 50 mm space between ice and surface at crack. 3rd cycle: Ice partially off, wgt shed: 0.35 kg.
22 Dec 82 ICED COATED SIDE ONLY	28.7	3.73	5.95	24		Deflate to 1.0 cm HOH: No cracks. Inflate to 35.8 cm HOH: No cracks, sheet appears lifted in places. 2nd cycle, deflate to 1.2 cm HOH: Horiz. crack on top and along side top to bottom. Sheet lifted at crack 13-19 mm, no shedding. * During lunch break, entire sheet fell off.
6 Jan 83 TEST # 1 BOTH SIDES COATED DEFLATE/INFLATE CYCLE	10.4	3.52	8.01	24		Deflate to 1.3 cm HOH: No cracks. Inflate to 38.0 cm HOH: @ 27.5 cm, many cracks both sides. Deflate: @ 7.8 cm HOH: 2 taps and portion of coated side off. Uncoated side unaffected. @ 1.7 cm HOH: Sheet lifted on coated side, no on uncoated. Few taps: Ice off coated side, uncoated side intact.

Date	Press. (cm HOH)	Weight (kg) Uniced	Weight (kg) Iced	Temp. (^{O}F)	Icing Time (min.)	Remarks
7 Jan 83	10.1	3.64	8.73	25	33	Inflate: Cracks appears @ 21.9 cm HOH. @ 25.6 cm, horiz. cracks along length of bag, lower half. Deflate to 1.2 cm: Sheet lifting at crack lines. Inflate: @ 29.9 cm HOH, 1/4 of lower section coated side off, uncoated section still on. One tap, coated side off, 1/2 uncoated side off.
TEST # 2 BOTH SIDES COATED INFLATE/DEFLATE CYCLE						
TEST # 3 DEFLATE/INFLATE CYCLE	25.5	3.64	6.38	24	22	Deflate: @ 4.2 cm HOH: Both sections; ice sheet lifted, 19-25 mm off surface in spots. @ 1.7 cm, small lower portion of coated side shed. All of ice sheet appears lifted. Any wind should shed ice sheet. Inflate to 25.4 cm HOH: One tap, most of ice off both sides. Wgt shed: 2.1 kg.
TEST # 4 INFLATE/DEFLATE CYCLE	25.3	4.20	7.30	24	45	Inflate to 37.7 cm HOH: Ice sheet intact. Deflate: @ 5.5 cm horiz. cracks appeared, more on uncoated side. Coated side appears to be lifted. @ 2.9 cm, coated surface lifted 6 mm. Uncoated side lifted at cracks. One tape most of coated side off, 1/2 of uncoated side off.
10 Jan 83	10.8	3.52	6.44	22	35	Inflate to 25.3 cm HOH: No cracks. Deflate to 1 cm HOH: No cracks, some lifting on coated side. Inflate: Cracks across coated side, entire length of upper side. Cracks ending just past uncoated side ice sheet. Thin ice layer, 0.8 mm. Many taps to shed ice.
TEST # 5 INFLATE/DEFLATE/INFLATE CYCLE						
11 Jan 83	9.9	3.62	8.28	23	30	Deflating: @ 1.7 cm HOH, far side coated section sheet lifted. Inflating: @ 24.6 cm HOH, horiz. cracks on both sides. Transverse cracks on coated side. Small portion at lifted spot on coated side off. Deflate to 1 cm HOH, much tapping needed to shed ice. Ice thickness to 1.5 mm.
TEST # 6 DEFLATE/INFLATE/DEFLATE CYCLE						
TEST # 7 EACH HALF COATED SEPARATELY						
Coated 1/2	10.9	4.01	6.10	24	22	Inflating to 26.3 cm HOH: Horiz. cracks on top half of both sides. Deflating to 1.0 cm HOH: No effects. Inflating to 24.6 cm HOH: Tapping, cracks all over, No shedding. Ice thickness to 1.3 mm.
Uncoated 1/2			8.26	24	22	
INFLATE/DEFLATE/INFLATE CYCLE						

Date	Press. (cm HOH)	Weight (kg) Uniced	Weight (kg) Iced	Temp. (^oF)	Icing Time (min.)	Remarks
12 Jan 83 EACH HALF COATED SEPARATELY						
Uncoated 1/2	10.1	3.87	5.88	23	25	Deflate to 1.0 cm HOH: No visible lifting, no change to surface. Inflate: @ 33.7 cm HOH, many horiz. cracks, 2-3 times more cracks on coated side. No shedding. Deflate to 3.9 cm HOH: 50% of coated side lifted, 10% uncoated side lifted. Inflating to 38.5 cm HOH: Ice shed with tapping.
Coated 1/2			8.[illegible]	23	25	
TEST # 8 DEFLATE/INFLATE/DEFLATE/INFLATE CYCLE						
TEST # 9 BOTH SIDES COATED	10.2	3.75	6.51	24	27	Inflating: @ 30.0 cm HOH, horiz. cracks. @ 38.6 cm, more cracks and lifting off both sides. Not as much as with test # 8. Deflate to 1 cm HOH: Sheet on both sides lifted 6 to 12 mm. Slight tap and sheet fell off. Wind might also do this.
			9.44	24	20	
INFLATE/DEFLATE/INFLATE/DEFLATE CYCLE						
13 Jan 83 HALVES COATED SEPARATELY						
Uncoated 1/2	10.3	3.52	5.93	23	20	Deflating to 1.0 cm: No effects. Inflating: @ 27.0 cm, cracks on both sides. @ 38.1 cm more cracks - more than with inflate/deflate cycle. Deflate: @ 0.9 cm HOH, * partial fall off ice sheet, 0.55 kg. Few taps and most of ice off. Ice thickness to 1.5 mm.
Coated 1/2			8.50	24	20	
TEST # 10 DEFLATE/INFLATE/DEFLATE CYCLE			7.95*			
Coated 1/2	10.5	3.96	6.30	25	20	Inflating: @ 28 cm HOH, cracks on uncoated side. @ 30 cm horiz. cracks across side - coated and uncoated. @ 34 cm, most of surface cracked. Deflate: @ 7.7 cm * portion of coated side fell off, 0.12 kg. @ 1.3 cm HOH, few taps and 80% of ice off. Crack photos, 26 and 27.
Uncoated 1/2			8.70	24	20	
TEST # 11 INFLATE/DEFLATE CYCLE			8.58*			
17 Jan 83 BAG RECOATED WITH COPOLYMER W/2 BRUSH COATS COATING SEQUENCE: EACH HALF COATED SEPARATELY. 1st COAT 15 MIN., 2nd COAT 10 MIN. ON EACH HALF.						
TEST # 12						
Uncoated 1/2	10.9	3.68	5.11	24	15	Inflating: @ 24.8 cm HOH, 1st cracks. @ 30.8 cm, two large cracks on uncoated side. Entire coated side appears lifted. @ 36.7 cm 1/4 of coated side fell off. Many cracks on uncoated side. Photos 34 and 35. Deflating: @ 1.6 cm, * on closing door, coated section fell off, wgt: 2.65 kg. Photo 36. Hard tapping to shed ice. Thickness, 2.8-3.7 mm at top. Coated side freezing in droplets, not marked with some holes, Photo O-3. Wgt shed after tapping: 2.58 kg.
Coated 1/2	11.6		7.09	24	15	
Uncoated 1/2	12.1		8.29	24	10	
Coated 1/2	11.2		9.38	24	10	
INFLATE/DEFLATE CYCLE	1.6		* 67.3 4.15 (after tapping)			

Date	Press. (cm HOH)	Weight (kg) Uniced	Weight (kg) Iced	Temp. (^{o}F)	Icing Time (min.)	Remarks
19 Jan 83 EACH HALF COATED SEPARATELY						
TEST # 13						
Coated 1/2	10.3	3.65	5.56	25	15	Inflate: @ 22 cm HOH, cracks appeared. @ 30 cm, lower portion of coated side off. Lower portion of both sides lifted. @ 38 cm,* lower 1/2 of coated side off. Wgt. shed: 0.74 kg.
Uncoated 1/2	11.7		7.05	25	15	
Coated 1/2	10.1		8.30	25	10	
Uncoated 1/2	6.4		9.23	25	10	
INFLATE/DEFLATE CYCLE						Deflate: @ 5 cm HOH,** most of ice sheet off. Wgt. shed: 1.82 kg. Ice thickness: Uncoated - smooth, 2.0 mm; Coated - pebbly, 3.0 mm. Ice sheet on top still on. 1 tap @ 1.2 cm HOH, most of ice off. Wgt. shed: 2.05 kg.
	38.0		* 8.49	25		
	5.0		** 6.67			
	1.2	1 tap	4.62			
20 Jan 83 TEST # 14						
Uncoated 1/2	10.7	3.67	4.85	25	15	Deflate: @ 2 cm HOH, bottom section coated 1/2 lifting. No lifting on uncoated 1/2. Inflate: @ 26 cm, horiz. cracks on both sides. @ 28 cm HOH, portion of bottom section coated side slid off. @ 38 cm, coated side appears lifted, uncoated side partially lifted.
Coated 1/2	11.8		6.83	25	15	
Uncoated 1/2	12.2		7.92	25	10	
Coated 1/2			9.27	24	10	
DEFLATE/INFLATE CYCLE						1 tap - 30% coated side off; 2 taps - 90% coated side off 60% uncoated side off
21 Jan 83 TEST # 15						
Coated 1/2	9.9	3.65	5.45	25	15	Deflate: @ 1 cm HOH, lower 1/4 coated side lifted. No other changes. Inflate: @ 21.4 cm HOH, 1st cracks on coated side, horiz, above midway up. Crack propagates into uncoated ice sheet. @ 27.7 cm, many cracks on coated side extending into uncoated side. @ 32.6 cm, photos 12-15. @ 38.5, lifting off denoted by color change. Most of coated side lifted off on midsection - starts on coated side and carries over to uncoated side. Rapid progression of color changes. Small section of uncoated side off, then both sides falling off*, wgt 0.80 kg. Most of coated side lifted. 50% of uncoated side appears white and still sticking 1 tap - much ice shed. 2 taps - 80% coated side off, 60% uncoated side off. Most of remaining ice on top of bag. Ice thickness: 2-2.5 mm. 1st tap - Ice shed: 1.87 kg. 2 taps - Ice shed: 0.46 kg.
Uncoated 1/2	11.0		6.74	25	15	
Coated 1/2	10.6		8.19	25	10	
Uncoated 1/2	10.8		9.23	25	10	
DEFLATE/INFLATE CYCLE						
	38.9		* 8.43	25		
	38.9	1 tap	6.56	25		
	38.9	2 taps	6.10	25		

Date	Press. (cm HOH)	Weight (kg) Uniced	Weight (kg) Iced	Temp. (^{o}F)	Icing Time (min.)	Remarks
24 Jan 83	TEST # 16					
Coated 1/2	10.7	3.74	5.00	27	15	Inflating: @ 22.5 cm HOH, cracks starting on coated section, *propagating into uncoated side. @ 25.0 cm, coated* section lifted, uncoated still on and white. Photos 15-17. @ 38.5 cm, small lower portion of coated side off.* Wgt shed: 0.20 kg.
Uncoated 1/2	12.2		6.05	28	15	
Coated 1/2	11.6		6.94	27	10	
Uncoated 1/2	14.6		7.73	29	10	
INFLATE/DEFLATE CYCLE						
	28.5		* 7.53			Deflating: @ 15.8 cm HOH, *bottom portion of coated side* lifted off and hanging. @ 6.7 cm, coated section lost about 1/2 of ice. Ice shed: 0.81 kg. @ 2.2 cm, portion of uncoated side off.** Wgt shed: 0.5 kg. After few taps - most of ice off. Ice shed: wgt 1.91 kg.
	6.7		6.72			
	2.2		6.16			
	1.4		4.25			
26 Jan 83	TEST # 17					
Uncoated 1/2	10.8	3.75	4.42	27	15	Inflating: 1st cracks, horiz., starts in coated sheet and propagates into uncoated sheet. @ 38.0 cm HOH, cracks on top of coated section, none on uncoated side. 1/4 of *top section coated side lifted. None uncoated side. Some* ice shed from coated side.* Wgt: 0.05 kg.
Coated 1/2	10.0		5.78	28	15	
Uncoated 1/2			6.52	28	10	
Coated 1/2			7.43	28	10	
INFLATE/DEFLATE CYCLE						
	38.0		* 7.38	28		Deflating: @ 1.9 cm HOH, top section of coated side off.** Ice shed: wgt 0.50 kg. One section coated side lifted 25-30 mm. Photos 22-29. @ 1.7 cm, *upper section coated* side lifted 70 mm. 1 tap: entire coated section off, 90% of uncoated section off. Wgt shed: 2.81 kg. Any wind should also shed ice.
	1.9		** 6.88			
	1.7		1 tap 4.07			
27 Jan 83	TEST # 18					
Coated 1/2	11.4	3.72	4.99	28	15	Demo for visitors. Cracks propagating from coated to uncoated side. Inflate/deflate cycle. Ice fell off uncoated side first.
Uncoated 1/2	11.0		5.98	28	15	
Coated 1/2	11.0		6.96	28	10	
Uncoated 1/2	11.5		7.78	28	10	
27 Jan 83	TEST # 19	COATING 1/2 OF BAG ONLY				
Coated 1/2	11.0	3.72	4.96	28	15	Inflate: @ 21.2 cm HOH, 1st horiz. cracks. @ 32.2 cm. many cracks, all directions. Photos 31-32.
2nd Coat	13.7		5.82	26	10	
INFLATE/DEFLATE CYCLE						
	1.0		* 5.54			Deflate: @ 1.0 cm HOH, some ice off.* Wgt shed: 0.28 kg. 1 tap - 1/4 of ice off; 4 taps - most of ice off.

Date	Press. (cm HOH)	Weight (kg) Uniced	Weight (kg) Iced	Temp. (^{o}F)	Icing Time (min.)	Remarks
31 Jan 83	TEST # 20 COATING 1/2 OF BAG ONLY: OPERATING PRESS: 5.1 cm HOH.					
Uncoated 1/2	5.2	3.70	4.59	28	15	
2nd Coat	5.4		5.19	28	10	Inflate: @ 15.9 cm HOH, 1st cracks. @ 21.2 cm, many cracks. @ 27.3 cm, bottom section off.* Ice shed, wgt: 0.38 kg. 1 tap - ice shed: wgt 0.43 kg.
	INFLATE ONLY					
	27.3		* 4.81	28		
			1 tap 4.38	28		
	TEST # 21 COATING 1/2 OF BAG ONLY					
Coated 1/2	5.0	3.92	4.56	28	15	Inflate: 1st cracks @ 11.8 cm HOH. 50% lifted. @ 37.9 cm, no ice off.
2nd Coat	4.6		5.44	27	10	
	INFLATE/DEFLATE CYCLE					Deflate: @ 4.6 cm HOH, 1 tap: ice almost all off. Ice shed wgt: 0.96 kg.
	4.6		1 tap 4.48	28		
1 Feb 83	FOLLOWING TESTS: BOTH SIDES COATED SEPARATELY WITH SHIELD IN BETWEEN (DISCONTINUITY BETWEEN ICE SHEET ON COATED AND UNCOATED SIDES.)					
TEST # 22						
Coated 1/2	5.9	3.73	4.92	28	15	Inflate: 1st crack @ 12.9 cm HOH on coated side. @ 15.7 cm 1st crack on uncoated side. @ 20.1 cm, many cracks on coated side and ice sheet lifted off both sides. Only one horiz. crack - mid height - on uncoated side, multiple cracks on coated side. Photos 21-31. @ 30.1 cm, more cracks on uncoated side. @ 35.0 cm, some ice off both sides.* Wgt shed: 0.28 kg. Lower half shedding ice, more off uncoated side. Photo 34.
Uncoated 1/2	5.7		5.92	28	15	
Coated 1/2	6.0		6.83	28	10	
Uncoated 1/2	5.6		7.52	28	10	
	INFLATE/DEFLATE CYCLE					
	35.0		* 7.24	28		
			** 6.92			
	4.4		*** 6.75			
	2.1		1 tap 4.10			Deflate: More ice off uncoated side.** Wgt shed: 0.32 kg. @ 4.4 cm HOH, ice off coated side.*** Ice shed, wgt: 0.32 kg. Photo 35 before tap, Photo 36 after tap. Ice shed: wgt. 2.65 kg.

Date	Press. (cm HOH)	Weight (kg) Uniced	Weight (kg) Iced	Temp. (^{o}F)	Icing Time (min.)	Remarks
1 Feb 83						
TEST # 23	SHIELD IN BETWEEN					
Uncoated 1/2	5.6	3.74	4.52	28	15	Inflate: 1st crack on coated side @ 15.7 cm HOH, at midpoint. @ 18.5 cm, one horiz. crack all the way across coated side. @ 20.0 cm, many cracks across entire coated sheet. No cracks on uncoated side. Photos 5-7. @ 23.8 cm HOH, 1st crack on uncoated side, just above midpoint of sheet. @ 29.1 cm multiple cracks on uncoated side. Many cracks on both sides. @ 33.6 cm HOH, ice off coated side.* Wgt:0.08 kg. @ 41.1 cm, much more ice off coated side.** Wgt: 0.41 kg. @ 40.7 cm, more ice off coated side.*** Wgt: 0.17 kg. Almost none of uncoated side.
Coated 1/2	5.8		5.66	28	15	
Uncoated 1/2	6.1		6.32	28	10	
Coated 1/2	4.7		7.26	28	10	
INFLATE/DEFLATE CYCLE						
	33.6 *		7.18	28		
	41.1 **		6.77	23		
	40.7 ***		6.60	28		
	4.3		4.35	28		Deflate: @ 4.3 cm HOH, Photo 5 before tap, Photo 6 after. Shed ice, Wgt: 2.25 kg.
3 Feb 83						
TEST # 24	WITH SHIELD IN BETWEEN					
Coated 1/2	4.9	3.71	4.96	28	15	Inflate: 1st crack just below midpoint on coated side @ 15.7 cm HOH. @ 19.5 cm, three big cracks coated side, above midpoint and across entire side - horiz. and branches. Many cracks and sheet lifting on coated side. Nothing on uncoated side. @ 25.4 cm HOH, one crack lower portion on uncoated side. Coated side all cracked and lifted. Uncoated sheet intact @ 34.0 cm, some ice off both sides.* Wgt shed: 0.43 kg. @ 37.5 cm HOH, uncoated side, many cracks. @ 38.3 cm, no changes.
Uncoated 1/2	7.7		5.86	28	15	
Coated 1/2			6.78	28	10	
Uncoated 1/2	8.0		7.65	28	10	
INFLATE/DEFLATE CYCLE						
	34.0		* 7.22	28		
	1.3		1 tap 4.21	28		Deflate: @ 1.3 cm HOH, Photo 21 before tap, Photo 22 after. Wgt shed: 3.01 kg.

Date	Press. (cm HOH)	Weight (kg) Uniced	Iced	Temp. (^oF)	Icing Time (min.)	Remarks
3 Feb 83						
TEST # 25	WITH SHIELD IN BETWEEN					
Uncoated 1/2	5.2	3.74	4.58	28	15	Inflate: @ 15.2 cm HOH, 1st crack on coated side, below midpoint. @ 26.8 cm, major cracks all over coated side and sheet lifting. One horiz. crack across uncoated section but sheet not lifted. Coated side - some ice off and almost all lifted. @ 35.9 cm, major cracks all over uncoated side. @ 39.0 cm, ice off both sides in equal amounts.* Wgt shed: 0.26 kg. Photos 27 and 28.
Coated 1/2	6.7		5.78	28	15	
Uncoated 1/2	5.7		6.45	28	10	
Coated 1/2	5.6		7.34	28	10	
INFLATE/DEFLATE CYCLE						
	39.0	*	7.08			
	8.3	**	6.41			
	3.7	1 tap	4.40			Deflate: Most of sheet on coated side lifted. Wind or tap should shed ice. Uncoated side also lifted and should shed with wind or tap. @ 8.3 cm HOH, major portion of coated side off.** Wgt shed: 0.67 kg. Photos 29 and 30. @ 3.7 cm HOH, Photo 31 before tap, Photo 32 after tap. Wgt ice shed: 1.94 kg.

APPENDIX B: PHOTOGRAPHS

Figure B1. Test data monitoring and inflation/deflation systems (manometer, load cell readout and inflation/deflation valves).

Figure B2. Icing patterns, copolymer-coated surface left, uncoated right, continuous sheet.

Figure B3. Icing pattern, copolymer-coated surface.

Figure B4. Icing patterns, copolymer-coated surface left, uncoated right, continuous sheet.

Figure B5. Multiple crack formation from coated to uncoated ends during inflation cycle, continuous sheet.

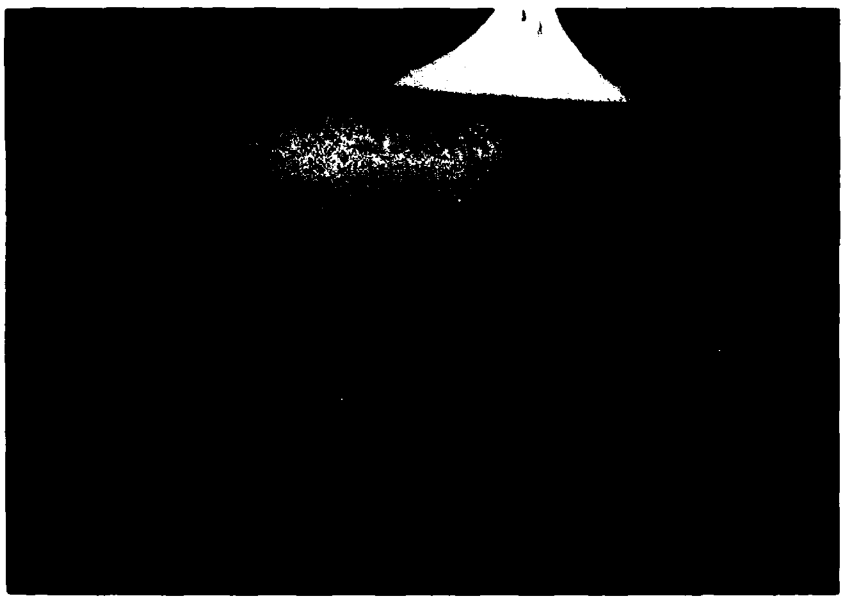

Figure B6. Multiple cracks, coated surface, continuous sheet from coated to uncoated ends.

Figure B7. Lift-off of sheet at crack lines; coated end, deflation cycle.

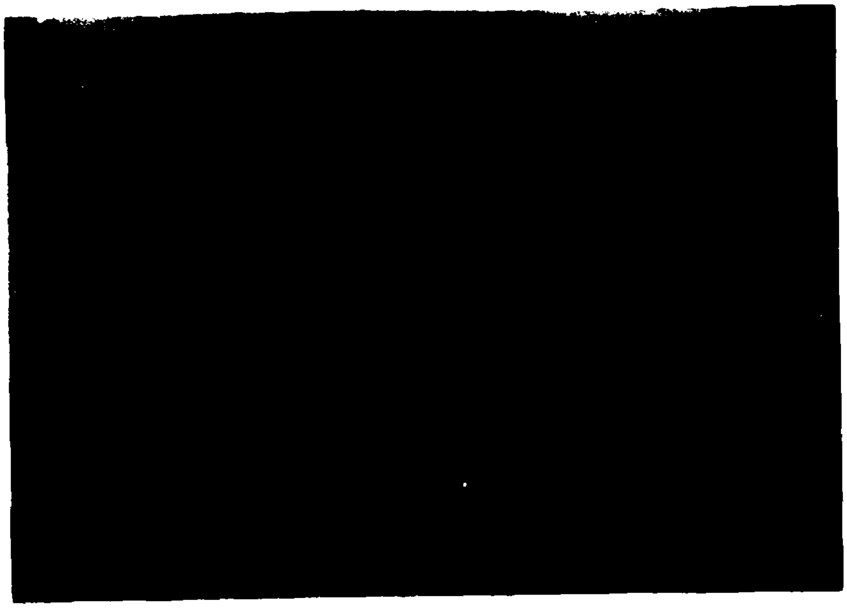

Figure B8. Lift-off of sheet at crack lines; coated end, deflation cycle.

Figure B9. Lift-off of sheet at crack lines; coated end, deflation cycle.

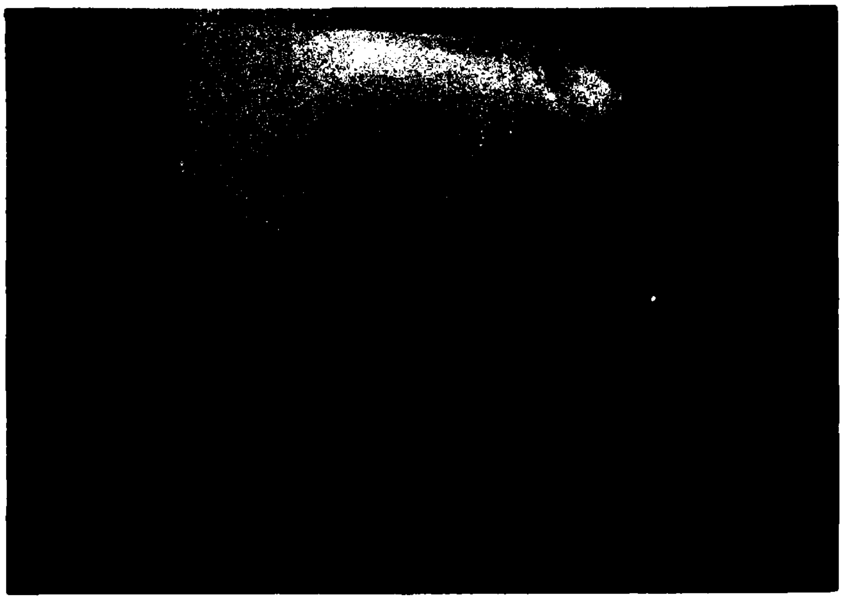

Figure B10. Ice sheet lifted from surface (dark area is lifted).

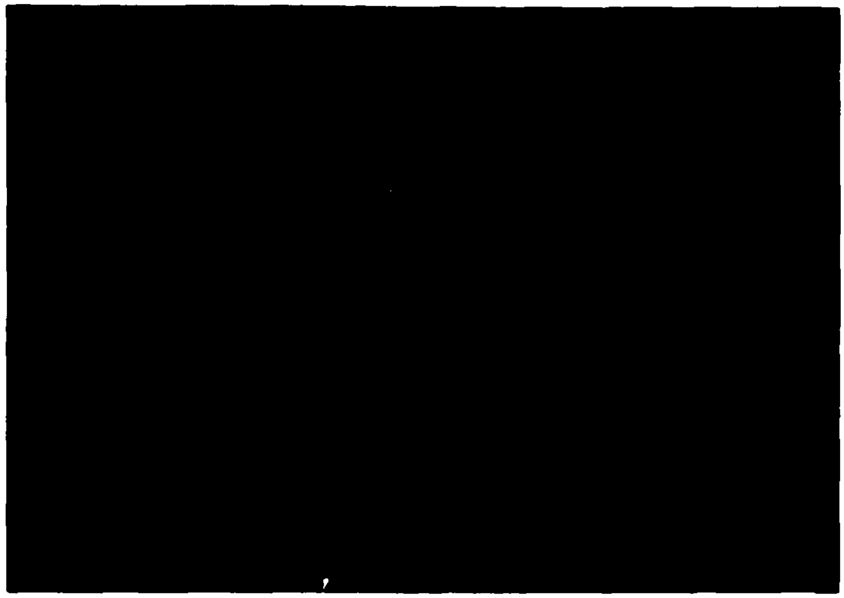

Figure B11. Ice sheet lifted from surface (dark area is lifted).

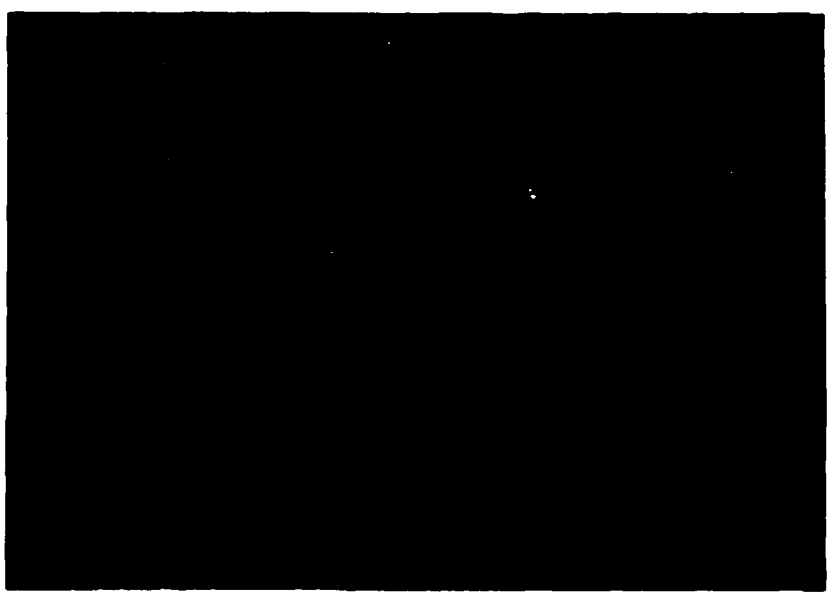

Figure B12. After inflation/deflation cycle, Test 21.

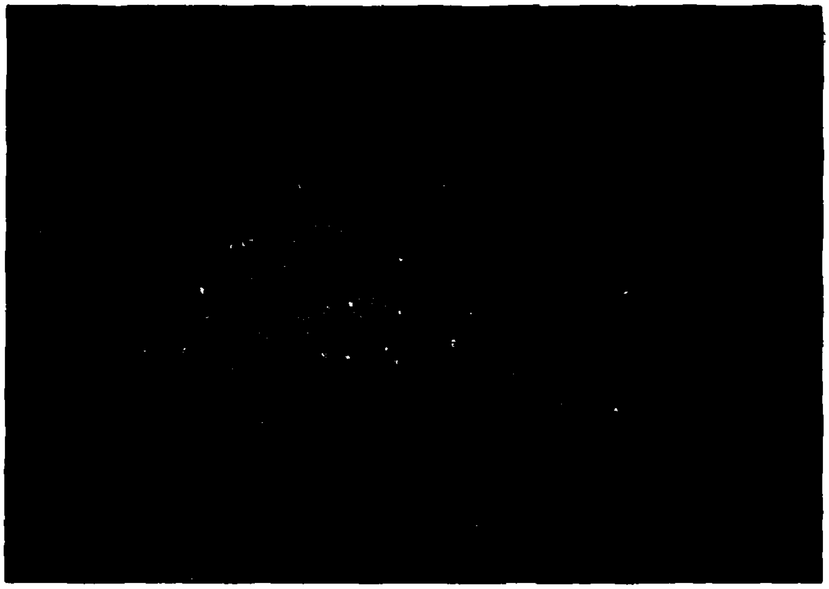

Figure B13. Icing with shield between coated and uncoated ends.

Figure B14. Ice sheet with discontinuity between coated and uncoated ends.

Figure B15. Inflation cycle, cracks in coated-end ice sheet, 15 cm (6 in.) water inflation pressure, uncoated end intact.

Figure B16. Inflation cycle, first crack in uncoated-end ice sheet at 25.4 cm (10 in.) water inflation pressure.

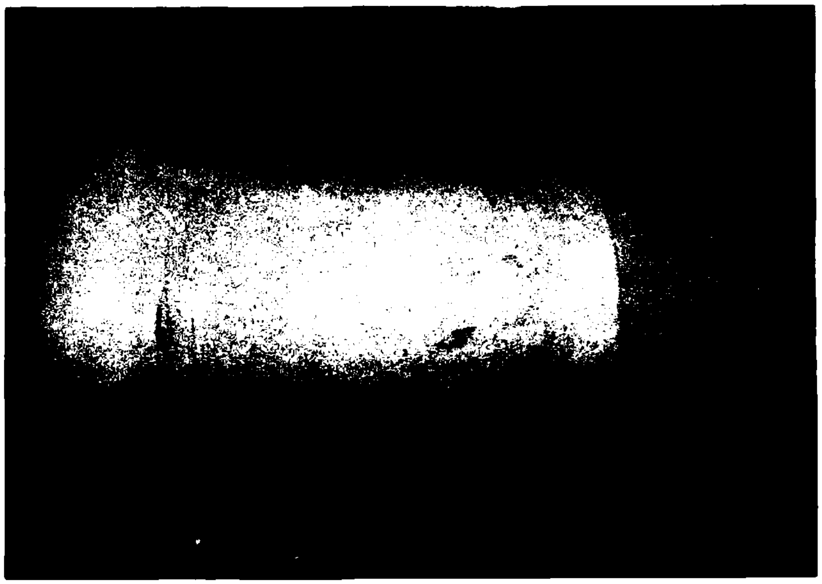

Figure B17. Inflation cycle, Test 22, self-shedding, left end coated, right end uncoated.

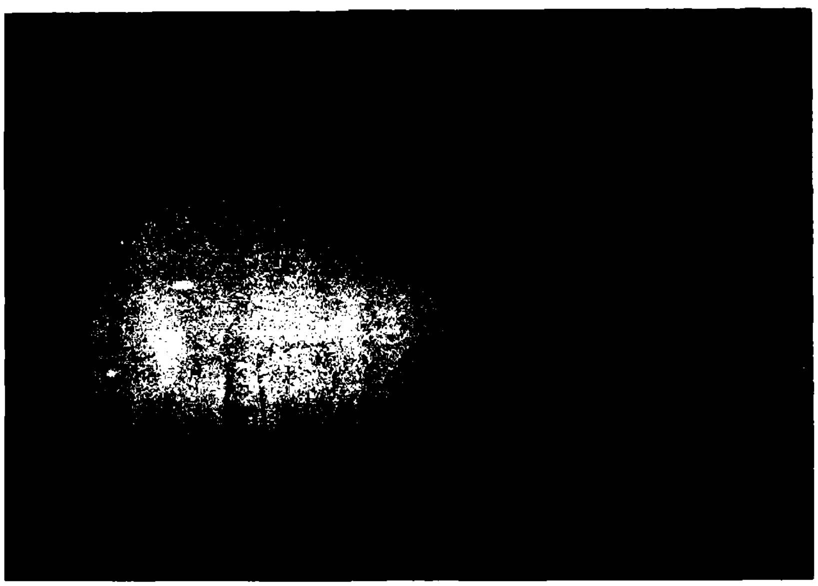

Figure B18. Inflation cycle, Test 23, self-shedding, left end coated, right end uncoated.

Figure B19. After inflation/deflation cycle and tap-induced vibration, Test 25; left end coated, right end uncoated.

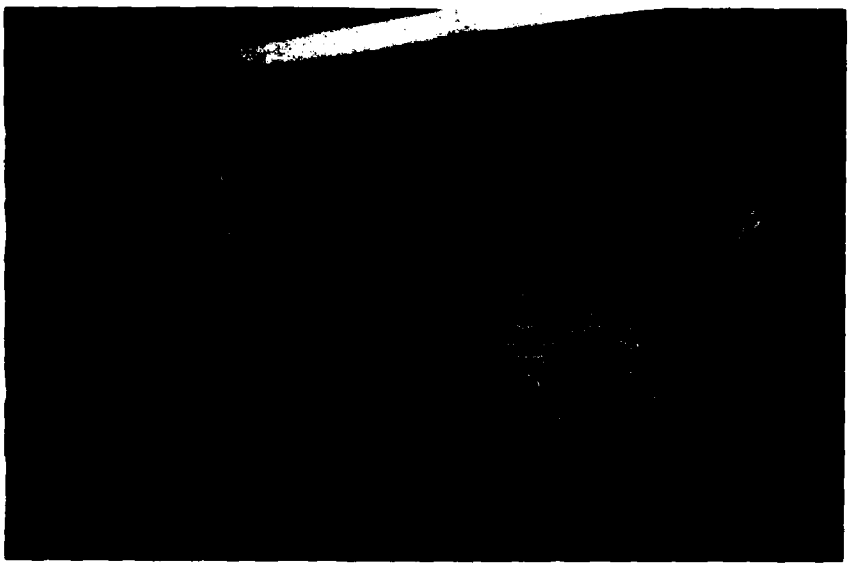

Figure B20. Compressed air spray system, icing with shield between coated and uncoated ends.

Figure B21. Aerostat system moored to ground platform at Camp Ethan Allen Training Center, Vermont.

Figure B22. Copolymer-coating of aerostat.

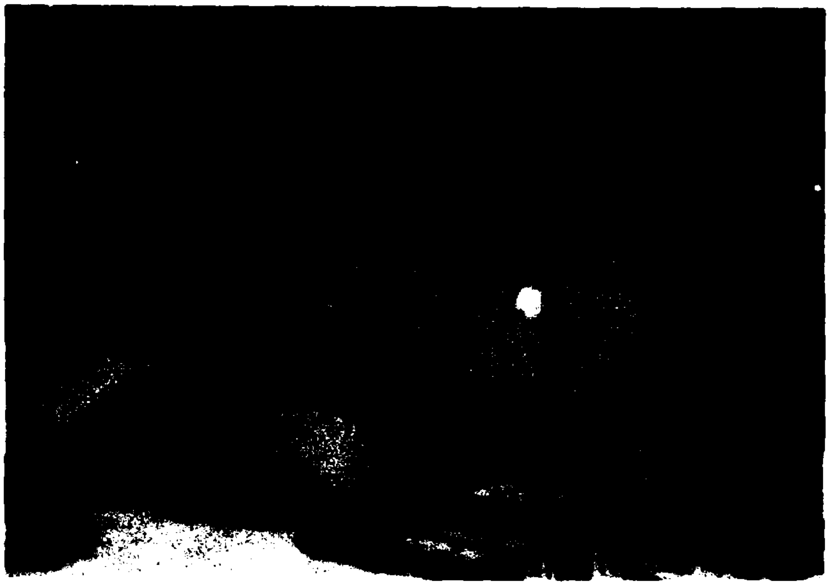

Figure B23. Copolymer application with roller using mobile "cherry picker."

Figure B24. Roller coating of fins with copolymer.

Figure B25. Rime ice on aerostat tether line.